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Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan

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ABSTRACT

Climate change has adverse effects at global, regional and local level. Heat wave events have serious contribution for global warming and natural hazards in Pakistan. Historical (1997–2015) heat wave were analyzed over different provinces (Punjab, Sindh and Baluchistan) of Pakistan to identify the maximum temperature trend. Heat accumulation in Pakistan were simulated by the General Circulation Model (GCM) combined with 3 GHG (Green House Gases) Representative Concentration Pathways (RCPs) (RCP-4.5, 6.0, and 8.5) by using SimCLIM model (statistical downscaling model for future trend projections). Heat accumulation was projected for year 2030, 2060, and 2090 for seasonal and annual analysis in Pakistan. Heat accumulation were projected to increase by the baseline year (1995) was represented in percentage change. Projection shows that Sindh and southern Punjab was mostly affected by heat accumulation. This study identified the rising trend of heat wave over the period (1997–2015) for Punjab, Sindh and Baluchistan (provinces of Pakistan), which identified that most of the meteorological stations in Punjab and Sindh are highly prone to heat waves. According to model projection; future trend of annual heat accumulation, in 2030 was increased 17%, 26%, and 32% but for 2060 the trends were reported by 54%, 49%, and 86% for 2090 showed highest upto 62%, 75%, and 140% for RCP-4.5, RCP-6.0, and RCP-8.5, respectively. While seasonal trends of heat accumulation were projected to maximum values for monsoon and followed by pre-monsoon and post monsoon. Heat accumulation in monsoon may affect the agricultural activities in the region under study.

1. Introduction

Climate change has adverse impacts on health, water, biodiversity and natural resources cited and accepted all over the globe (IPCC, 2014; Lu and Chen, 2016; Kikon et al., 2016; Nasim et al., 2016; Qasim et al., 2016; Abbas et al., 2017). Many developing countries of the world are suffering from climatic variations, and developed countries are trying to manage their anthropogenic activities for sustainable climate (Su et al., 2016). While discussing this issue at regional level it become more specific and climatic uncertainty is also increased. Anthropogenic

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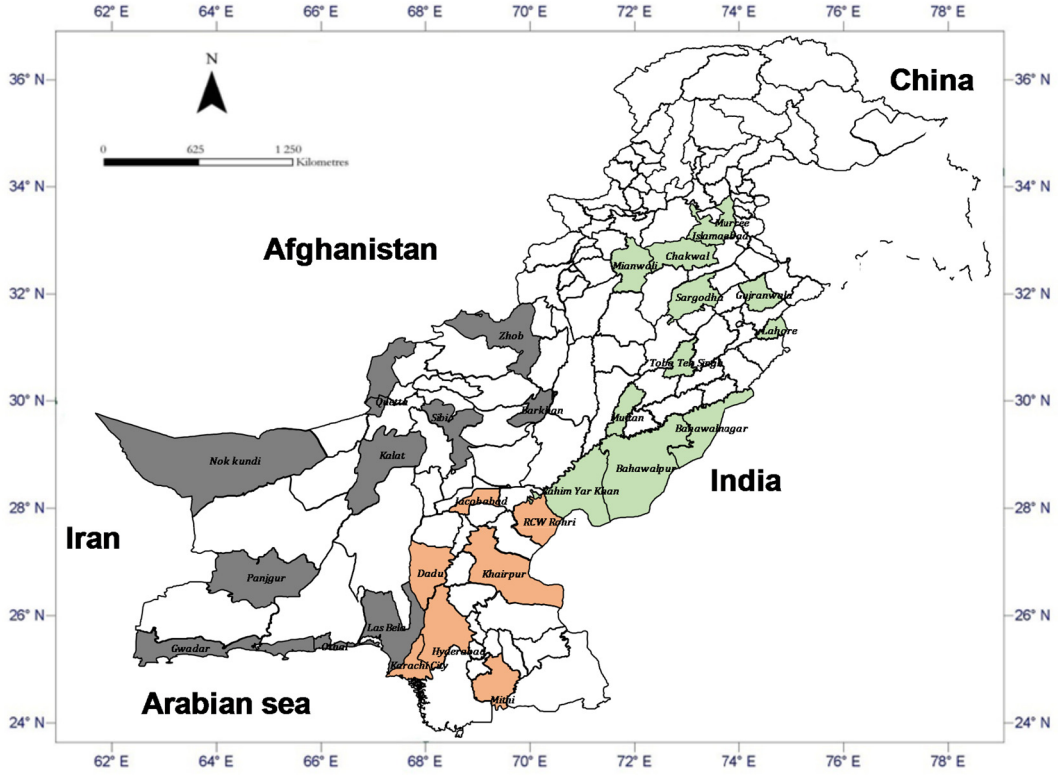

Fig. 1. Geographical representation of Pakistan with latitude and longitude.

activities are considered to be responsible for large scale regional climate disasters (Chakraborty et al., 2015; Amin et al., 2015; Amin et al., 2016; Adeel et al., 2017; Rozina et al., 2017). As with the industrialization the rate of GHG emission/concentration has increased which directly or indirectly raise the heat accumulation and uneven temperature variations (Montzka et al., 2011; Jinsart and Thepanondh, 2014; Ali et al., 2016). During 20th century the global temperature has increased by 0.76 °C and first decade of 21st century was recorded as the warmest years of the globe (Qi and Wang, 2012; Wang and Fu, 2013; IPCC, 2014; Dong and Huang, 2015; Lu and Chen, 2016; Anjum et al., 2016; Deo et al., 2017). According to the World Meteorological Organization (WMO) occurrence of heat waves has increased during 2001–2010 which increased the death rate by 2300 folds (136,000 deaths), European heat wave (~70,000 deaths), and Russian (~11,000 deaths) as compared to the last decade of 20th century (WMO, 2013). Almost 20% death rate has increased with overall temperature and heat stress, outcomes of the extreme weather events (Lu and Chen, 2016). In the last decade of 19th century, warming trends were reported almost all part of the world (Nasim et al., 2011; WMO, 2013; Rohde et al., 2013; Su et al., 2016; Ishaq and Memon, 2016; Khan et al., 2016; Nasim et al., 2017a; Lakho et al., 2017). It is worldly accepted that climatic variations will also trigger the unpredicted climate and weather events; also enlarge the intensity, duration, and extent of climate extreme events (Field et al., 2012). South Asian regional studies reported the variations in heat accumulation due to extreme climate events (Qian et al., 2011; Qi and Wang, 2012; Wang and Fu, 2013; Chakraborty et al.,2015; Dong and Huang, 2015; Feng et al., 2015; Fattahi et al., 2015; Ghajarnia et al., 2015; Lu and Chen, 2016; Easterling et al., 2016; Kikon et al., 2016; Jan et al., 2017; Javaid et al., 2017). Urban heat island or heat accumulation for last 50 years in china caused the temperature rise 0.2 °C to 0.3 °C for overall warming. In mega cities of India heat accumulation had been reported with the temperature rise 2 °C to 3 °C within just 15 years (Kikon et al., 2016; Mehmood et al., 2016). Global warming caused by the high temperature due to the increased duration of hot days and frequent heat waves (IPCC, 2013).

Pakistan is not exempted from these climatic extreme events. Pakistan lies in climatically warm geographical region which is vulnerable to climate extreme events like heat waves, drought, and floods (PMD, 2012). Temperature increase in this region is accepted to be higher than the global temperature variations. Glaciers of the Hindu Kush, Karakoram, and Himalayan ranges were receding rapidly due to heat accumulation which may enhance the risk of floods and extended droughts (IPCC, 2007; Rasul et al., 2008; Berthier et al., 2010; PMD, 2012). These climatic disasters may cause the serious threats to water, floods and energy security of the country (Chaudhary and Rasul, 2004). Risk of heat strokes, health diseases, and disturbance in settlement will rise with the variations in heat accumulation due to floods, heat waves, and droughts (Rasul et al., 2005; Haider et al., 2008; Maida and Rasul, 2011). Heat index was reported to increase from 1961 to 2007 in the country. Heat waves reported in Pakistan has killed > 200 peoples within a week in 2015 (PMD, 2015). Heat related disease and mortality rate (in animal and human) has increased because of extreme heat events during last decade. According to the Global Climate Risk Index 2014, Pakistan lies in third position among the most climate affected countries (Kreft and Eckstein, 2013).

In this region, a study reported the future projection showed a 4.0 °C temperature rise for 2100 (PMD, 2012). Heat accumulation is the by-product of climatic extremes which was more vulnerable to regional climate. Future projections for these climatic events may enhance the

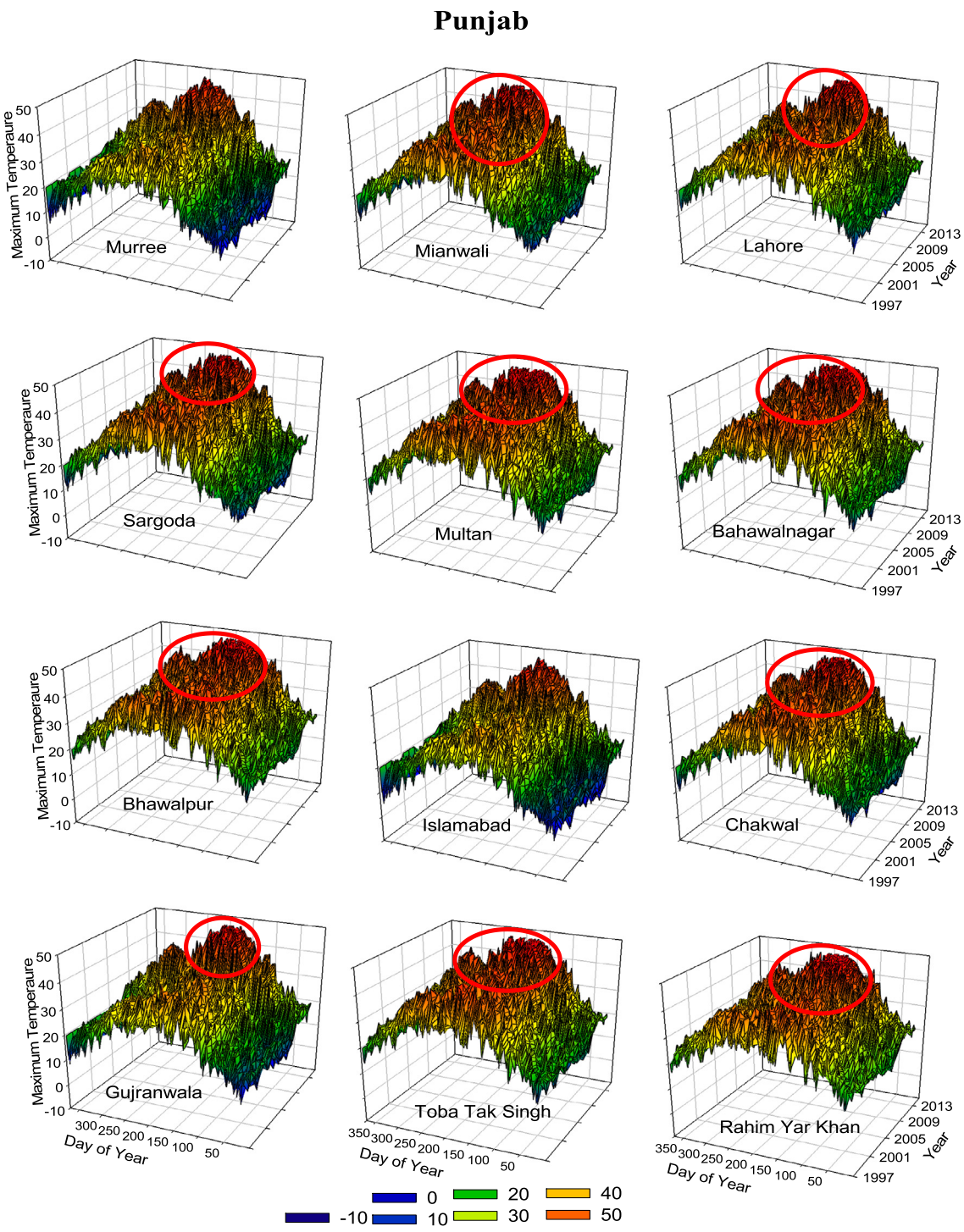

Fig. 2. Historical (1997–2015) trend analysis for daily maximum temperature (°C) to identify the heat wave in Punjab, province of Pakistan at different spatial scales.

chance for better sustainable adaptations (IPCC, 2014; Horton et al., 2015; Huang et al., 2017). Intergovernmental Panel on Climate Change (IPCC) issued Fifth Assessment Report (AR5) which use new climate models with collaboration of Coupled Model Inter-comparison Project Phase 5 (CMIP5) for future climate projection with GHG concentration scenarios (Taylor et al., 2012; IPCC, 2014; Deo and Sahin, 2015; Su et al., 2016). GCM parallel with GHG scenarios, newly developed three Representative concentration pathways (RCPs) which show low, median, and high GHG concentrations at the rate 4.5, 6.0, and 8.4-RCPs respectively (Sillmann et al., 2013; Chen et al., 2014; Singh and Goyal, 2016; Su et al., 2016). Similar climate projection application SimCLIM was developed to incorporate future projection upto 2100 (Yin et al.,

2013). General Circulation Models (GCM) were used to regulate the past climate change and project future climatic events (Xu et al., 2015; Lu and Chen, 2016). To capture the more reliable climatic changes at regional level, it's important that most appropriate GCM should be selected which accurately projected the present climate (Amin et al., 2016).

In this study, we have identified the historical heat wave events over different temporal (1997–2015) and spatial (Punjab, Sindh and Baluchistan) scales. To identify the future projections for heat accumulation by SimCLIM climate model for different regions of Pakistan. Heat accumulation patterns were projected for 2030, 2060, and 2090 decades and seasons and annual trends were analyzed. With these projections we have indicated the "*hotspots*" and heat accumulation pattern in different regions of Pakistan with visual representation.

2. Material and methods

2.1. Study area description

Pakistan is versatile in natural habitats and seasonal distributions from region to region. Its climate shows great variations in term of temperature from very low ' < 0 °C' for northern areas to extremely high value' > 55 °C' for different regions of Baluchistan province (Rasul et al., 2012). Pakistan lies in the region of south Asia with most abundant natural resources and climate variations. It shares its territory with India (East), China (north), Iran and Afghanistan (west), and Arabian Sea (South) as shown in Fig. 1. Agriculture sector of Pakistan is also vulnerable due to climate change impacts (Schilling et al., 2013; Ratnam et al., 2016; Amin et al., 2017a) and its geographic orientation (Iqbal et al., 2016; Nasim et al., 2017b). Based on tropical climate in Pakistan, there are huge deviations of heat accumulation on seasonal (winter, pre-monsoon, monsoon, and post-monsoon) and annual scales.

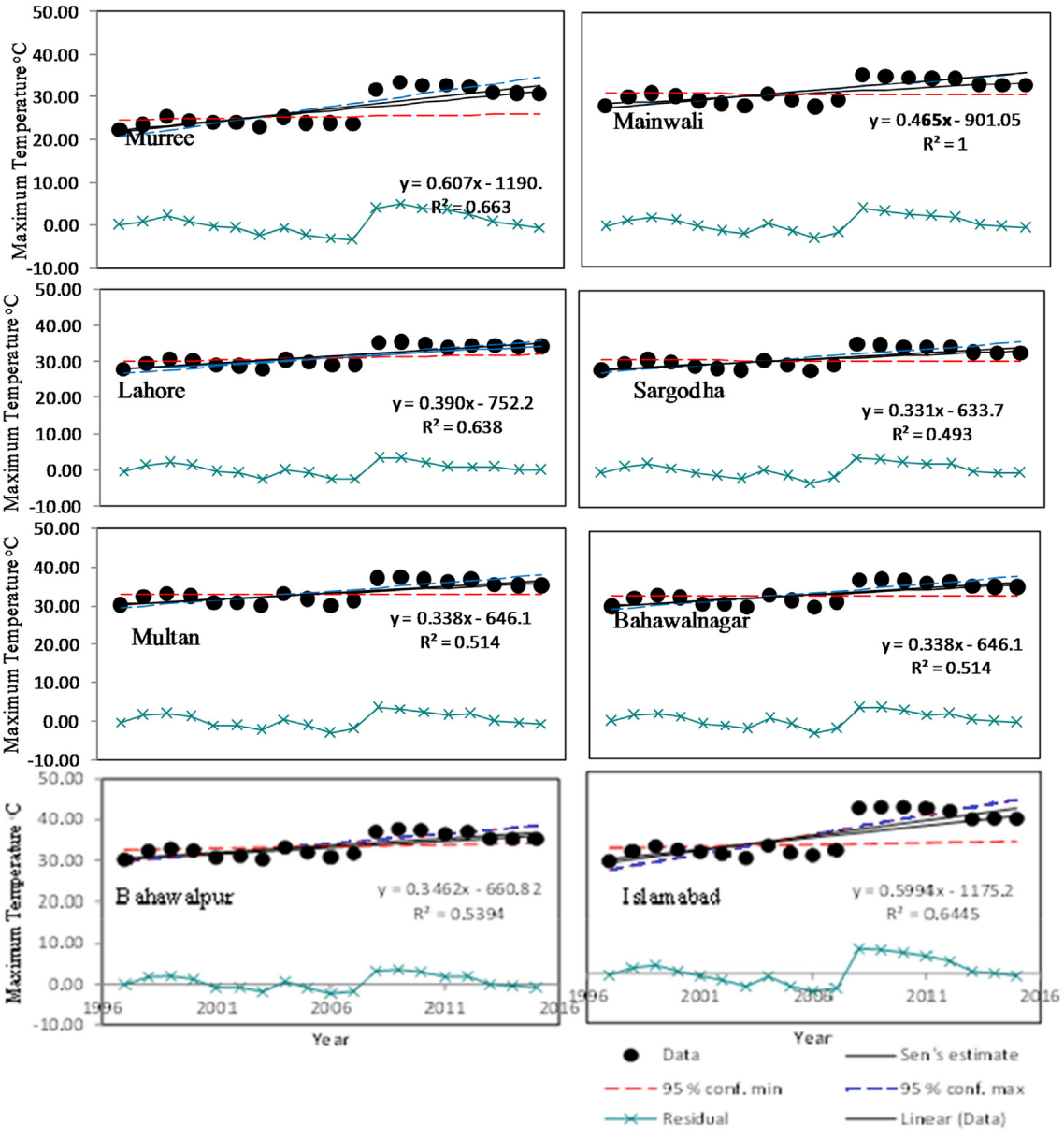

Fig. 3. Application of statistical analysis for trend estimation of maximum temperature with historical data (1997–2015) for Punjab.

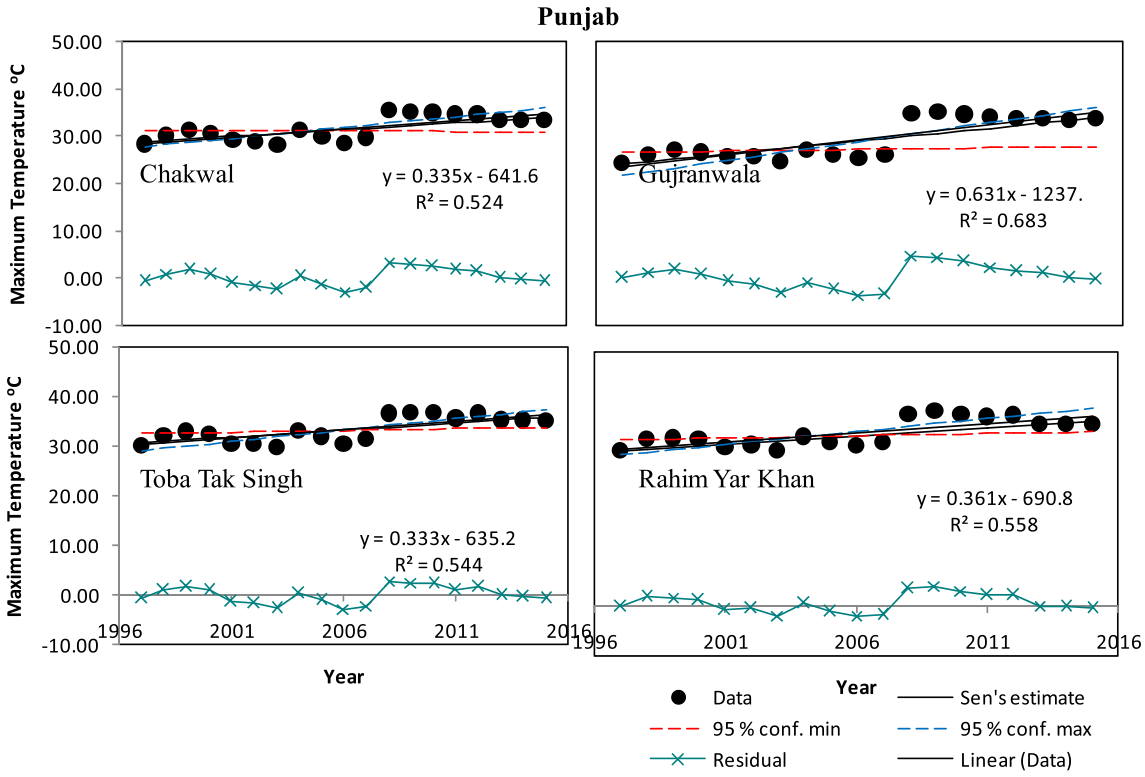

Fig. 3. (*continued*)

There is need of effective and on time management system in the climate change context to address all these issues. According to such drastic environmental and climatic constraints, there is need to adapt precaution to cope with the future safety challenge, by using recommended climate models. Different models and approaches have presently been utilized to estimate the future climate projections.

2.2. Historical heat wave trend identification

Historical data (1997–2015) set of daily maximum temperature recorded by Pakistan Meteorological Department (PMD) for 29 weather stations (from Punjab, Sindh, and Baluchistan) were used to identify the heat wave events. The daily maximum temperature variations for all the available stations of Punjab, Sindh and Baluchistan were derived to visualize the trend between the years and months (Figs. 2, 3, 4, 5, 6 and 7).

The heat wave events are identified using the daily maximum temperature for specified temporal and spatial scales as per recommendations by PMD (PMD, 2015). For identifying the heat waves over Pakistan maximum temperature varied from region to region for the period 1997–2015, were analyzed as shown in Figs. 2, 3, 4, 5, 6 and 7. We selected the heat wave event when the average maximum temperatures are greater than the standard deviation for > 8 days or more (Horton et al., 2015; Ratnam et al., 2016).

All the spatial and temporal distribution of the maximum temperature variations is verified for the days of the particular events to validate the PMD suggested recommendations.

The standard criteria recommended by PMD to identify heat waves (PMD, 2015);

(i) Heat wave will be considered when maximum temperature for understudy meteorological station reached > 45 °C for plains and > 40 °C for hilly areas.

(ii) When average maximum temperature of understudy station is equal to 42 °C then noted rise of 5 °C to 6 °C for 8 days or more are considered as heat waves.

(iii) When the maximum temperature for a station is more than 45°Cfor > 8 days than irrespective to normal temperature trend is to be considered as heat wave.

2.3. Model selection and description

Main focus of these approaches is to assess the climate impact by SimCLIM (statistical downscaling model for future trend projections). SimCLIM (software system) is a computer-based statistical tool to study variation over space, time and the climate variability effects. It is a customized type of Geographical Information System (GIS) which uses different tools for spatial analysis of the climate variability and linked impacts on different social-economic systems. Anyone can customize this model for spatial resolution and preferred geographical area and to associate impact models (Jinsart and Thepanondh, 2014; Ratnam et al., 2016).This application is an open framework which allows to customize the model for particular area by implement impact models. Degree days are an impact model (in SimCLIM) used to project the future heat accumulation for different temporal and spatial scales (Yin et al., 2013).

Heat accumulation in Pakistan has been projected by using SimCLIM. GCM is used to simulate the base and future climate with sensitivity level (variable). GHG representative concentration pathways (RCPs) are used parallel with GCM to project future climate (Yin et al., 2013; Su et al., 2016). Application of single GCM is not reliable to project the current climate accurately (Amin et al., 2016), accordingly ensemble method that was used to erect the future climate change

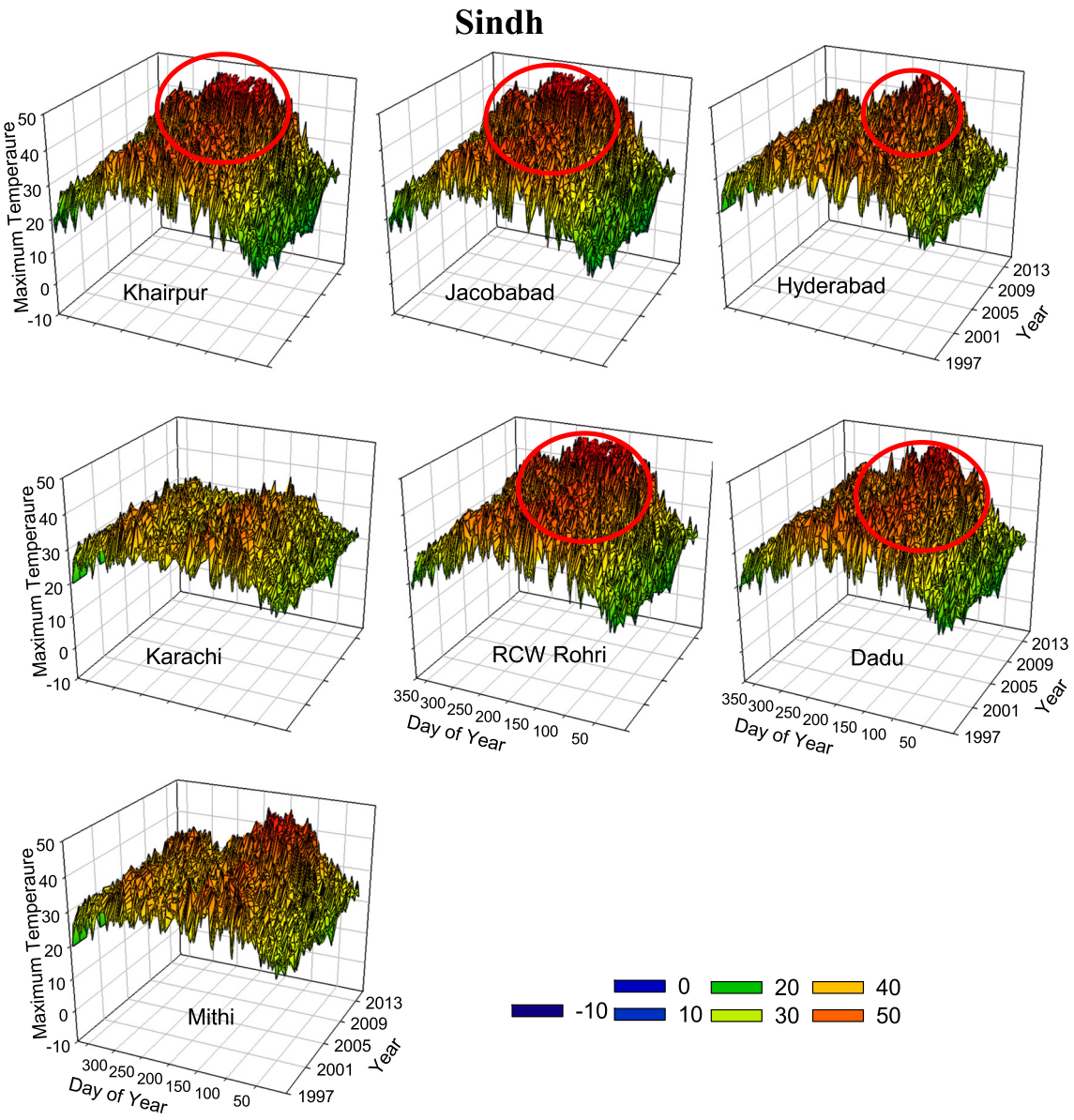

Fig. 4. Historical (1997–2015) trend analysis for daily maximum temperature (°C) to identify the heat wave in Sindh, province of Pakistan at different spatial scales.

scenarios. Application of more GCMs (ensemble) normalized the climate pattern values projected for future. For Pakistan GCMs (*ensemble*) were used to project the heat accumulation with RCPs (4.5, 6.0, and 8.5) for seasonal and annual projections (2030, 2060, and 2090). *For further detail about model, ensemble approach and statistical analysis had discussed in* Amin et al. (2017b).

3. Result and discussion

3.1. Identification of heat wave trend form historical data

The heat wave events for the plain and hilly regions of Pakistan are initiated from the average daily maximum temperature variations 62° E–78° E and 36° N–24° N (Fig. 1). We found out the significant heat wave events with the above mentioned criteria. Almost 73 events of heat waves were indicated over the period 1997 to 2015 only for 10 different weather stations of Punjab, 33 heat wave events at 5 weather stations of Sindh and 15 heat wave events at Baluchistan for selected 3 weather stations (Table 1). According to our assessment out of 12 understudy weather stations of Punjab, 10 weather stations has been identified for heat wave events. Maximum numbers of heat wave events are identified over Rahim Yar Khan for historical period (1997–2015) as shown in Figs. 2 and 3. Similarly, out of 7 metrological weather stations 5 are observed under the stress of heat waves with extreme values reported for Khairpur and RCW Rohi (Figs. 4 and 5). In Baluchistan among 10 understudy weather stations heat waves are identified at 3 locations; while maximum heat wave events observed over Nok-Kundi for 1997–2015 as given in Figs. 6 and 7. The composite of the heat wave over the period (1997–2015) for Pakistan shows significant maximum/day temperature variations, > 5 to 6 °C over the understudy regions (Figs. 2, 3, 4, 5, 6 and 7).

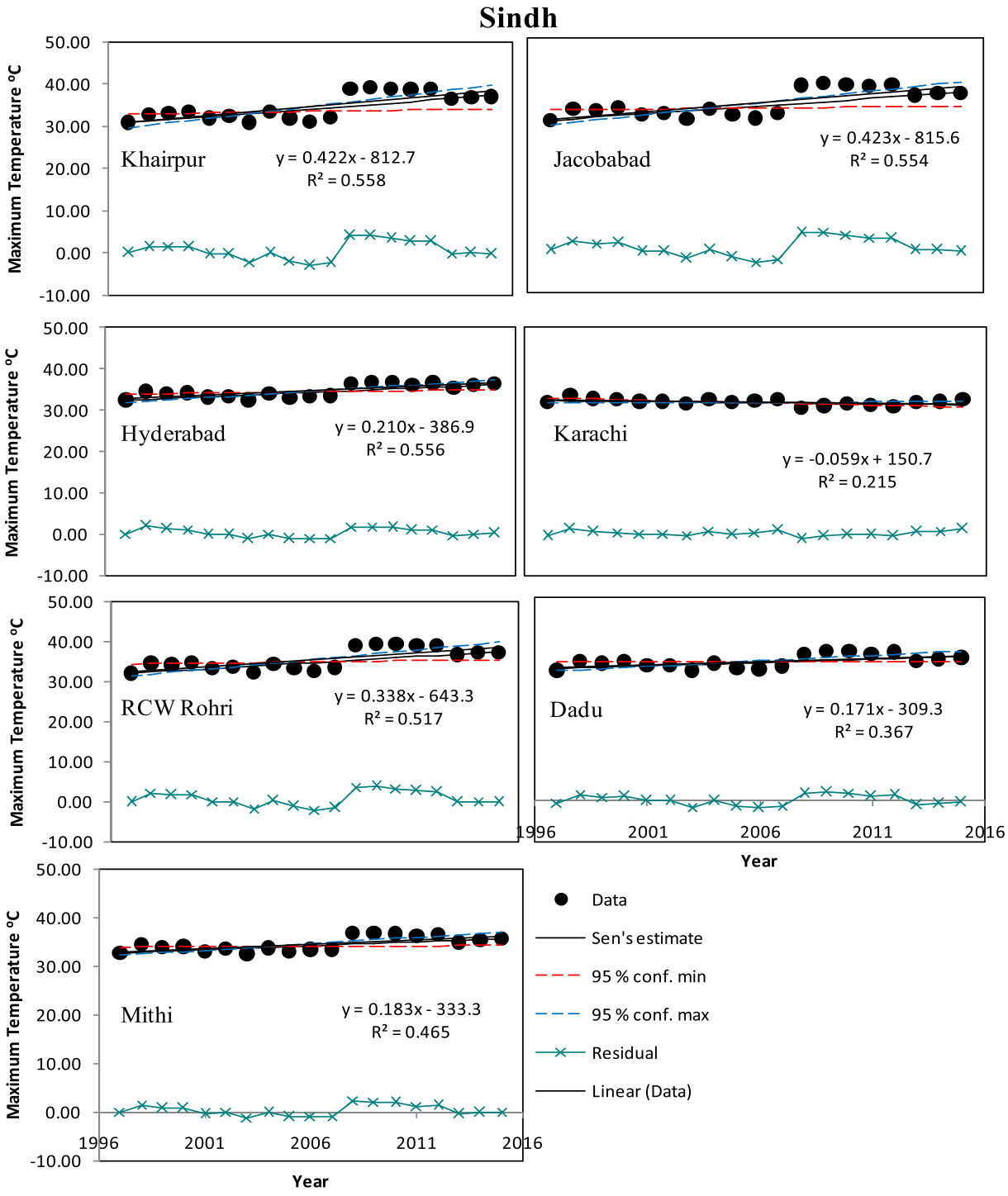

Fig. 5. Application of statistical analysis for trend estimation of maximum temperature with historical data (1997–2015) for Sindh.

3.2. Projection with different climatic scenarios for the 2030, 2060 and 2090s

The term heat accumulation is referred as thermal time which is expressed in degree days by the climate projection model as shown in Figs. 8, 9, 10 and 11. The projection and estimation of heat accumulation for a particular area is based on the temperature trend and thresholds. For a specific site temperature data was used through different built-in methods (single sine and double sine) to calculate the degree days. Development of degree days by these linear methods directly depends upon the maximum and minimum temperature (Jinsart and Thepanondh, 2014). SimCLIM statistical downscaling model was used to calculate the degree days for seasonal and annual based projections for Pakistan. From our result for heat accumulation in southern Punjab and Sindh were reported to be increased with climate change in Representative Concentration Pathways (RCPs) (4.5, 6.0, and 8.5) for

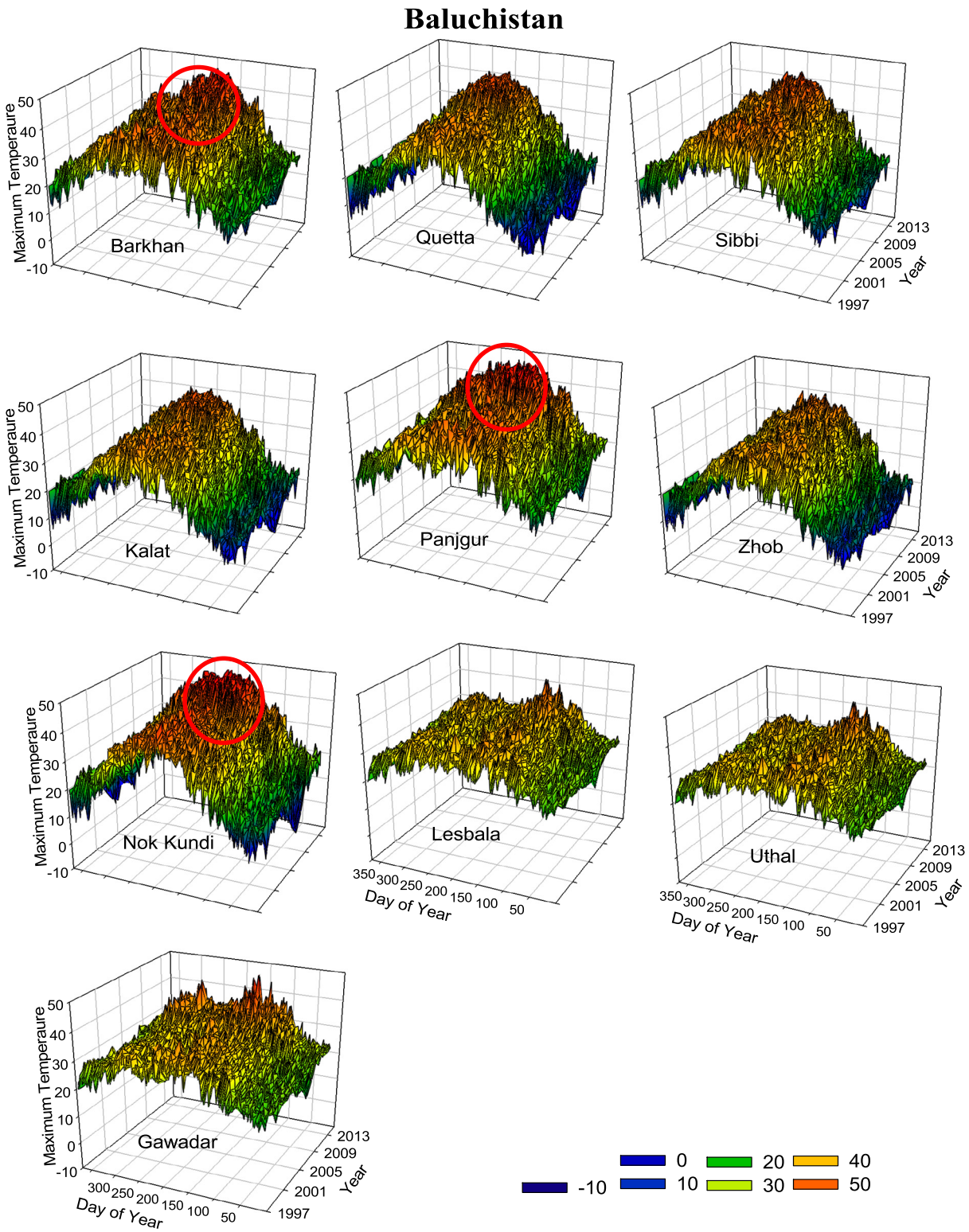

Fig. 6. Historical (1997–2015) trend analysis for daily maximum temperature (°C) to identify the heat wave events in Baluchistan, province of Pakistan at different spatial scales.

year 2030, 2060, and 2090. Intensity of annual heat accumulation decreased in upper Punjab and lower Sindh in 2090 as compared to projected year 2030 from baseline data available (Fig. 8). Heat waves risk was also reported to be increased in 2090 followed by 2060 projection in central part of Baluchistan.

3.2.1. Projection of annual heat accumulations

Projection of heat accumulation on annual basis has been shown in Fig. 8. Maximum heat accumulation projected for southern Punjab and upper Sindh to 2030 decreased w. r. t. baseline but it increased for 2060 followed by 2090. Maximum risk was reported in northern Sindh for

annual heat accumulation. Kazmi et al. (2014) reported the similar results for future climate change (temperature variations) in the country. Heat accumulation reported with maximum climate change scenario (RCP-8.5) 32%, 49%, and 140% for 2030, 2060, and 2090, respectively. Annual temperature rise reported for all over the country justified these resultsby Rasul et al. (2012), Abbas (2013), Abbas et al. (2013), Iqbal et al. (2016), Amin et al. (2016), and Amin et al. (2017c). Annual projection shows that maximum heat accumulation for 2030 followed by 2060 and 2090 may be cause due to global warming. Pre-monsoon and monsoon analysis are describedin the following sections.

3.2.2. *Projection of pre-monsoon heat accumulations*

Pre-monsoon season showed variation in heat accumulation for Baluchistan and Punjab, and its effect were found to be increasing in

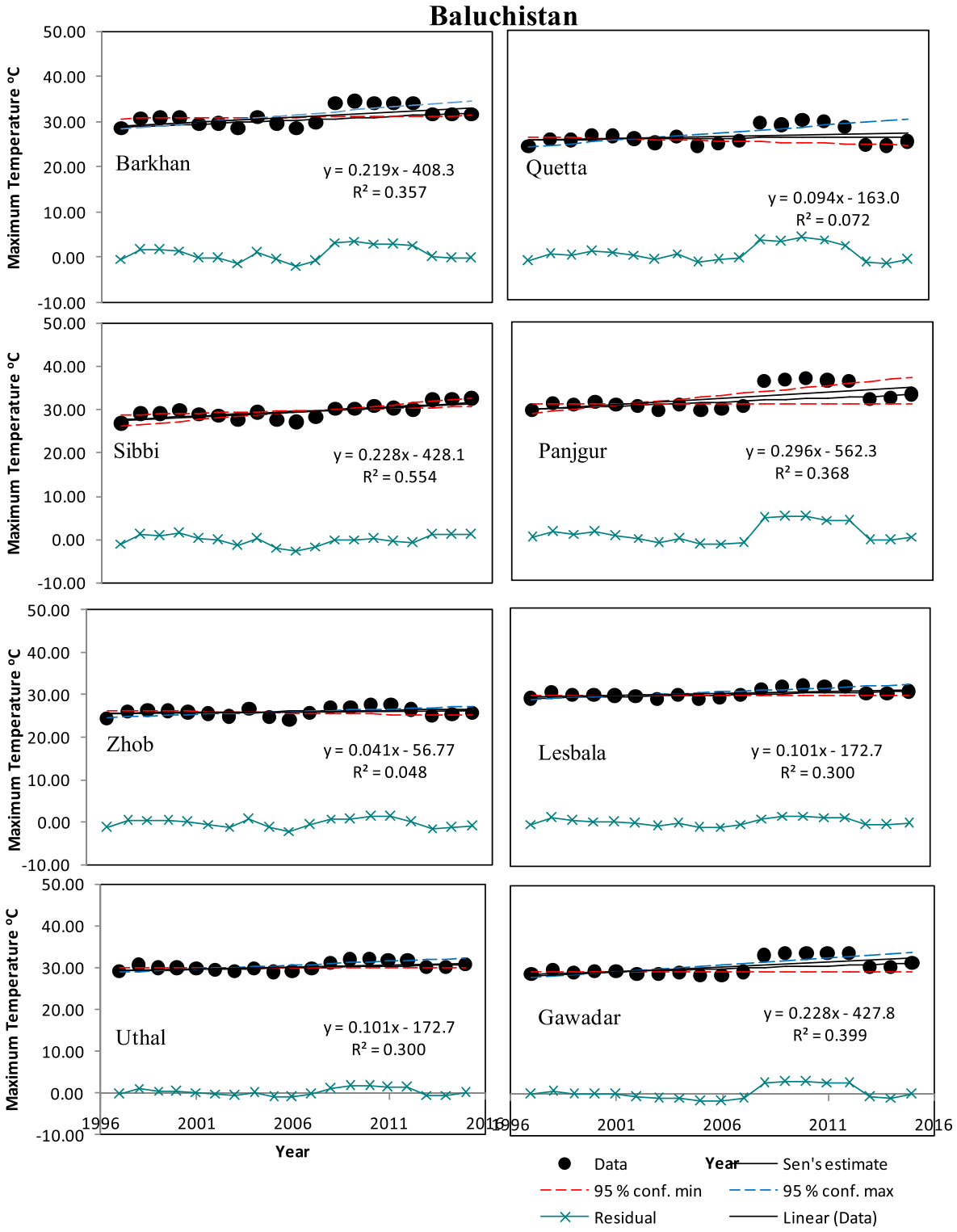

Fig. 7. Application of statistical analysis for trend estimation of maximum temperature with historical data (1997–2015) for Baluchistan.

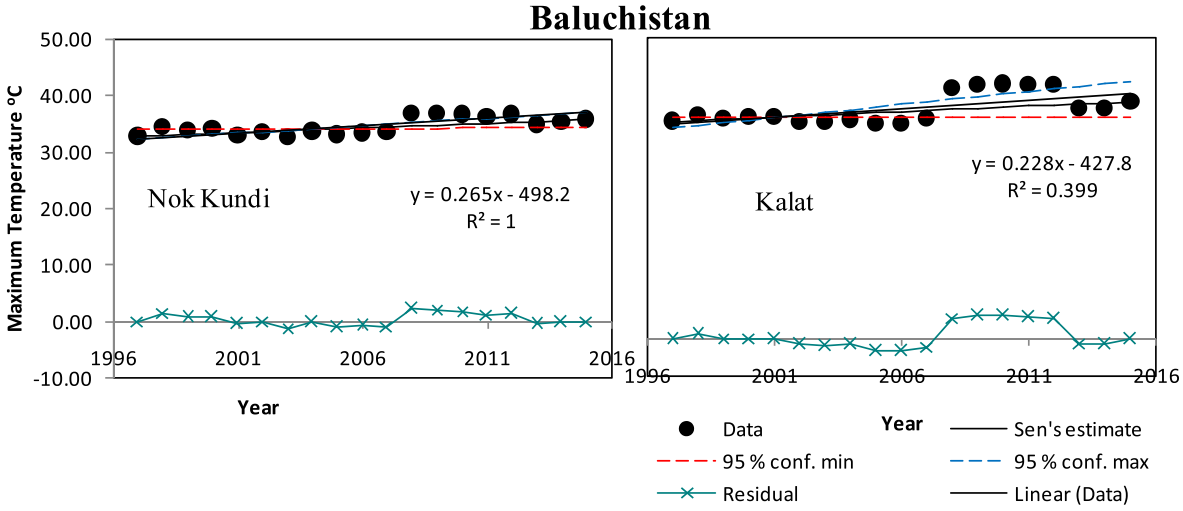

Fig. 7. (*continued*)

Table 1
List of heat wave events over provinces (Punjab, Sindh and Baluchistan) of Pakistan for different spatial and temporal (1996–2015) scales.

Punjab								
Mianwali	13–24 May; 1–11 June 2008	13–24 May; 19–30 June 2009	4–29 June; 10–21 May 2011	8 May–7 July 2012	5–19 June 2014			
Lahore	13 May–14 June 2010	13 May–6 June 2011	16 May–7 July 2012	4–22 June 2014				
Sargodha	13–25 May; 1–11 June 2008	13–25 May; 19–31 June 2009	21 May–4 June 2010	10–21 May; 8–28 June 2011	8 May–7 June 2012	5–19 June 2014		
Bhawalnagar	13 May–11 June 2008	13 May–14 June 2009	17 June–7 July 2010	24 Apr–28 June 2011	9 June–8 July 2012	17–27 May 2013	4–21 June 2014	
Bahawalpur								
Multan								
Toba Tak Singh	2 Apr–8 May 2008	14–31 May 2009	9 May–3 June 2010	24 Apr–28 June 2011	6 May–9 July 2012	17–26 May; 1–12 June 2013		
Rahim Yar Khan	25 Apr–8 May; 13 May–8 June 2008	8 May–25 June 2009	9–20 Apr; 6 May–10 July 2010	1 May- 8 July 2011	5 May- 7 July 2012	15–27 May 2013	26 May–11 June 2014	16–28 May 2015
Chakwal	13–24 May; 1–12 June 2008	14–31 May 2009	21 May–4 June 2010	4–28 June 2011	9 June–8 July 2012	5–21 June 2014		
Gujranwala	14 May–15 June 2009	21 May–5 June 2010	9–26 May; 4–27 June 2011	24 May–6 July 2012	4–21 June 2014			

Sindh								
Khairpur	27 Apr 13 June 2008	7 May- 17 July 2009	9–20 Apr 2010	1 May- 17 July 2011	15 May–12 June 2012	15 May–12 June 2013	26 May–25 July 2014	16–27 May; 17–30 June 2015
Jacobabad	27 Apr–14 June 2008	7 May–17 July 2009	9–20 Apr; 11 June–6 July 2010	5 May–9 July 2012	15 May–11 June 2013	26 May–26 July 2014		
Hyderabad	11–29 May 2009	11–31 May 2010	22 May–4 June 2012					
RCW Rohi	26 Apr–14 June; 1–21 July 2008	8 May–11 July 2009	9 Apr–7 June 2010	2 May–17 July 2011	5 May–9 July 2012	14 May–11 June 2013	27 May–24 July 2014	15–29 May 2015
Dahu	12–31 May 2008	8–30 May; 3–21 June 2009	29 May–10 June 2011	19 May–6 June 2012				

Baluchistan					
Barkhan	21–28 May 2010	4–28 June 2011	16 June–6 July 2012		
Nokkundi	28 May–17 June; 1–21 July 2008	15 July–19 Aug 2009	18–30 June 2010	3–17 June; 4–17 July 2011	27 June–20 July; 6–25 Aug 2012
Panjgur	8–18 May 2009	19–27 May 2010	6–24 May 2011	21 May–9 June 2012	

Sindh for 2030 followed by 2060 and 2090. Most part of the Punjab effected by heat stress projected in all temporal scales. High intensity of heat accumulation reported in Sindh for RCP-4.5,that projected increase rate of 35%, 74%, and 88% and RCP-6.0 projected heat wave increase rate 36%, 66%, and 113% while RCP-8.5 projected the high intensity of heat accumulation 41%, 116%, and 130% for 2030, 2060, and 2090, respectively (Figs. 4 and 5). Increase in temperature was also reported by Sheikh et al. (2009), Khattak et al. (2011), and Iqbal et al.

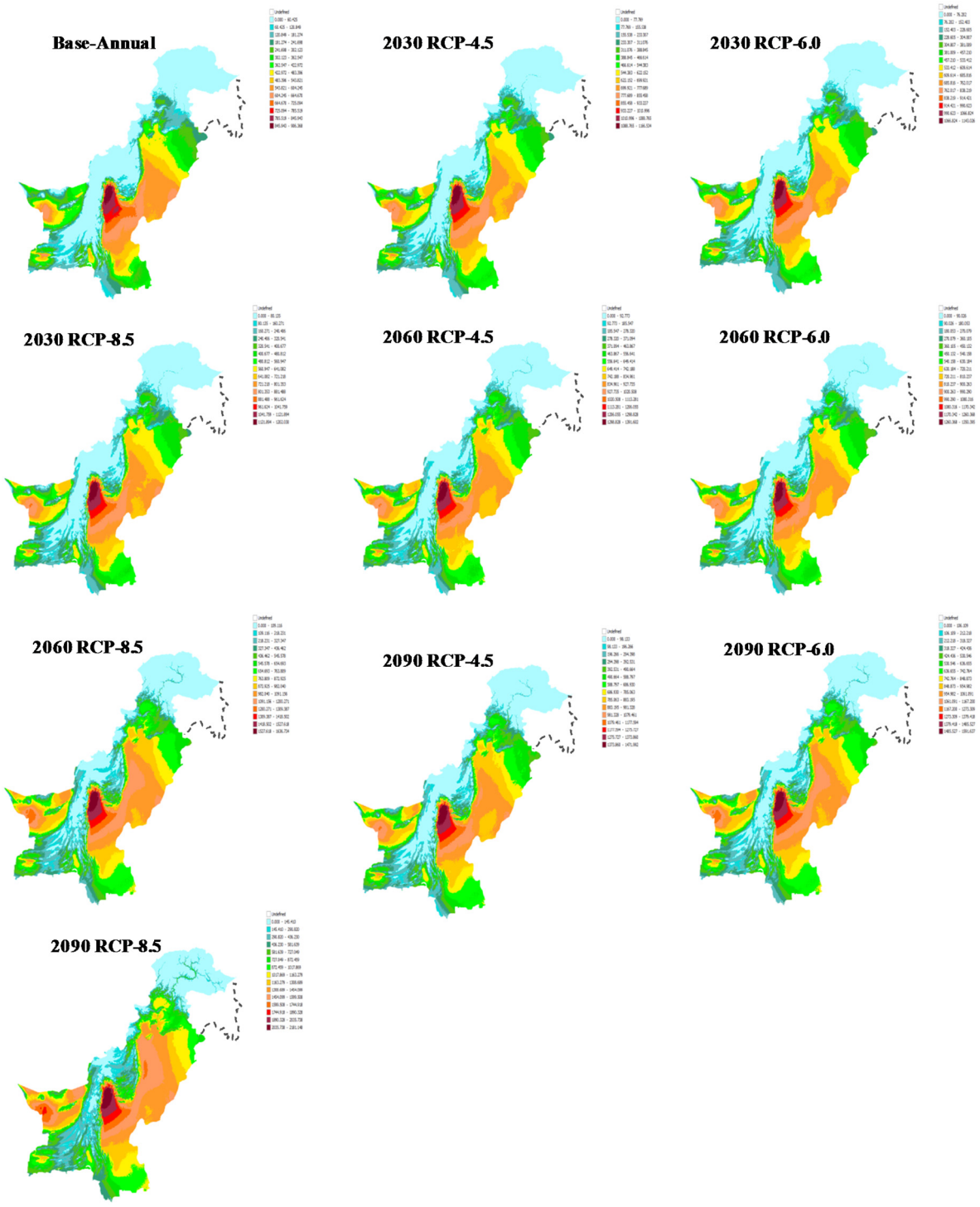

Fig. 8. Projections of Annual heat accumulation by spatial degree day model for 2030, 2060, and 2090 with Representative concentration pathways.

(2016) in most parts of Pakistan. During the Pre-monsoon season (March, April and May) almost 95% of areas in Pakistan showed increase in temperature (Iqbal et al., 2016). This sharpest temperature rise caused heat accumulation in future which may result in rise in snow and glacier melting in northern areas of Pakistan (Easterling et al., 1997). Maximum heat accumulation was projected by the model for southern Punjab and Sindh. High risk of heat accumulation was reported for upper Sindh as compared to base line data. Intensity of risk in Sindh was reported to increase with projected year 2030 followed by 2060 and 2090. Risk of heat accumulation due to temperature rise caused early maturity of wheat in pre-monsoon season which might-affect the final crop yield (Hussain et al., 2005). According to our findings, heat accumulation in highly populated areas of Pakistan will be increasedupto 26%, 49%, and 75% from base line data available with RCP-6.0, but RCP-4.5 showed low heat accumulation 17%, 54%, and 62%, while this trend will be increased for RCP-8.5 with projected

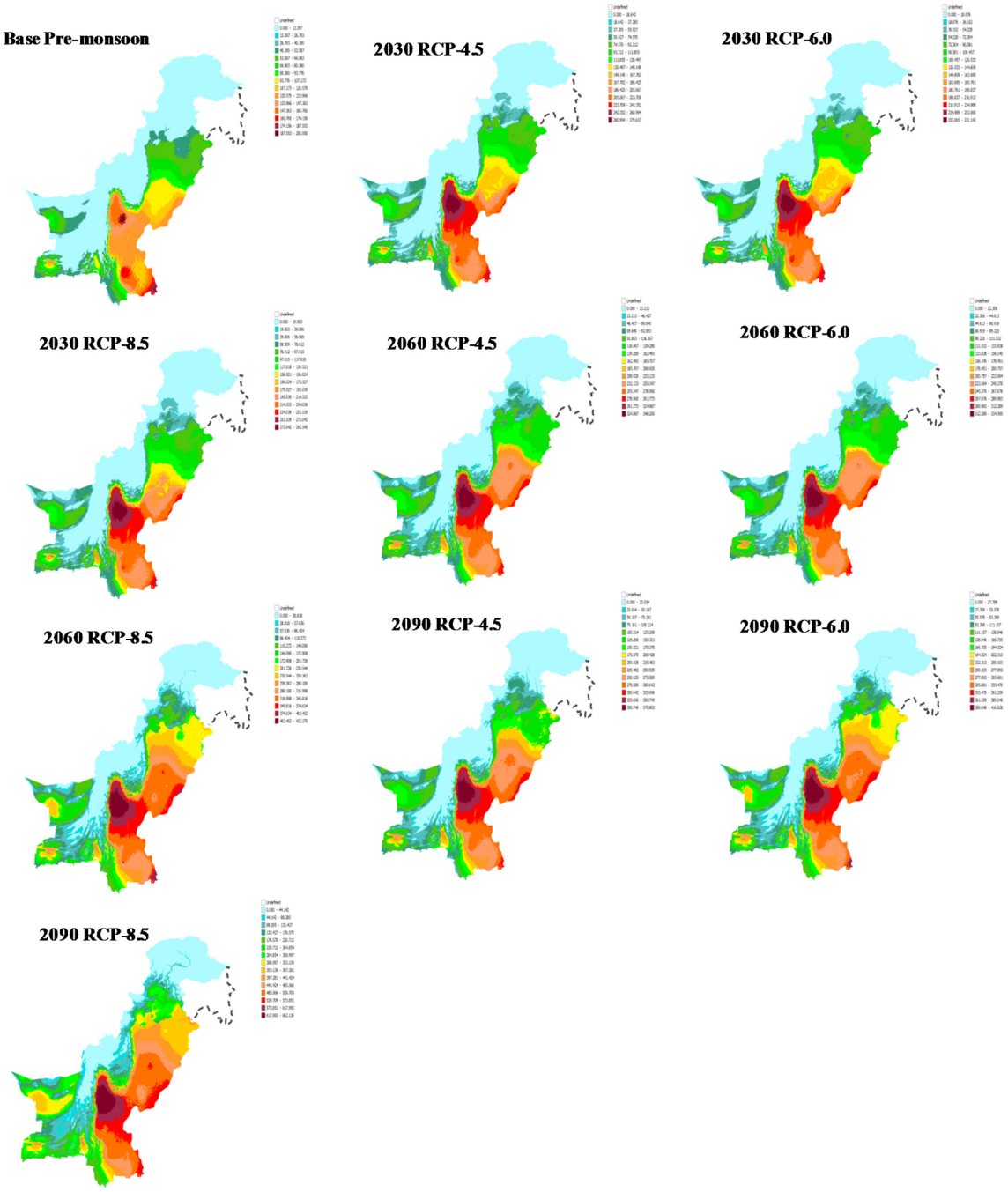

Fig. 9. Projections of Pre-monsoon heat accumulation by spatial degree day model for 2030, 2060, and 2090 with Representative concentration pathways.

rate 32%, 86%, and 140% for 2030, 2060, and 2090 respectively (Table 2).

3.2.3. Projection of monsoon heat accumulations

High heat accumulation in Monsoon season was observed in Punjab, Sindh, Baluchistan and most of the regions of Khayber Pakhton Khwa (Fig. 10). Similar trends were reported by Pakistan Meteorological Department (PMD) for different spatial scales especially for Sindh (PMD, 2012). Projected heat accumulation with respect to the base line data showed high percentage change for RCP-4.5 variation trends 22%, 63%, and 56%, and these trends decreased for RCP-6.0 which showed 24%, 33%, and 52% while for higher concentration levelRCP-8.5 showed the trend 24%, 34%, and 93% for 2030, 2060, and 2090, respectively as shown in Table 2. Months which are characterized for monsoon season showed a decrease in heat accumulation in comparison with pre-monsoon season as shown in Fig. 10. Similarly, maximum temperature has been decreased in most of the areas of Pakistan (Iqbal et al., 2016). But maximum temperature decreased for monsoon justified by similar study Sheikh et al. (2009) in all climatic regions except Baluchistan province. Intensity of projected heat accumulation increased in some regions of Baluchistan in 2030 followed by 2060 and 2090 (Fig. 10).

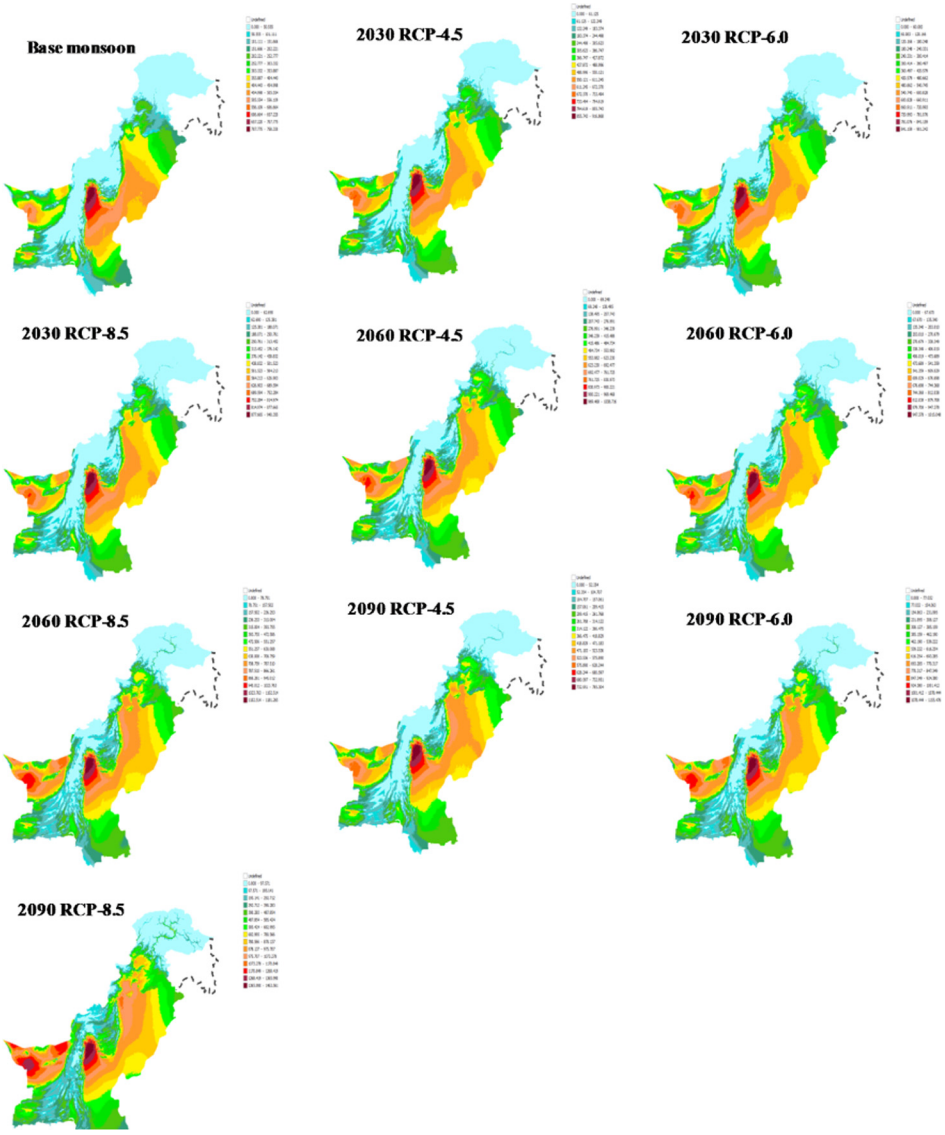

Fig. 10. Projections of Monsoon heat accumulation by spatial degree day model for 2030, 2060, and 2090 with Representative concentration pathways.

3.2.4. Projection of post-monsoon heat accumulations

Minimum heat accumulation was projected for the Post-monsoon season (December, January and February) in the whole country. Base line data was not available for this season but projected heat accumulation for 2030 was projected to increase particularly in Sindh region. Northern Sindh was highly prone to the intensity of heat projected by SimCLIM in Fig. 11. Uneven increase in maximum temperature and risk of heat waves has been increased in most of the region of Sindh (highly populated) (Pakistan Metrological Department, 2015). Area under the threat of heat accumulation was increased for 2060 followed by 2090 in Sindh. In 2090 heat accumulation was projected to increase with different scenarios, as RCP-8.5 reported the maximum threat in southern Punjab, Sindh and in lower parts of Baluchistan. Different studies justify our result which showed that maximum temperature had been increased for these regions (Abbas et al., 2013; Iqbal et al., 2016).

4. Conclusion

The results indicated that Pakistan heat wave events have significantly increased in last decade due to climate change, as trend has identified from historical data analysis. Similarly, model projected (2030, 2060, and 2090) the high risk of drought and heat waves in Sindh and southern Punjab (provinces of Pakistan) due to heat accumulation. Pre-monsoon and monsoonal projected heat accumulation will adversely affect the crop-yield parameters. These results showed that drought and heat waves could be frequent in projected years. Different *hotspots* are identified for annual and seasonal GCM model projection in different temporal and spatial scales with different emission scenarios will enable us for adaptive measures. This study also indicates the exposure of climate models projections for the climate risks in Pakistan and timely enables us for adaptive measures. This study emphasis on the application of climate models for future climate assessments to attain sustainable development and natural recourse

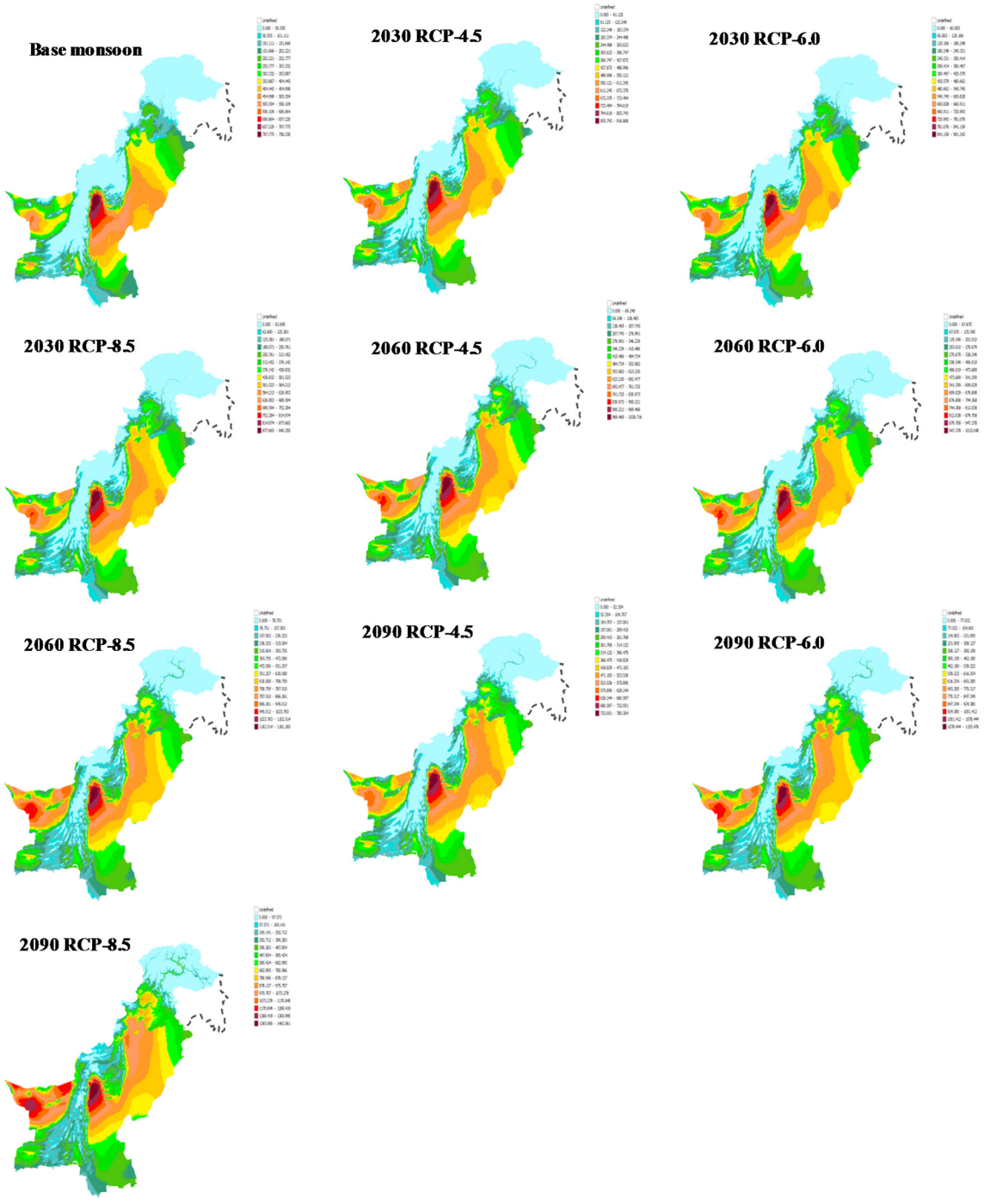

Fig. 11. Projections of Post-monsoon heat accumulation by spatial degree day model for 2030, 2060, and 2090 with Representative concentration pathways.

Table 2
Detail description of highest heat accumulation projection for different temporal scale.

	Base	2030						2060						2090					
RCP		4.5		6.0		8.5		4.5		6.0		8.5		4.5		6.0		8.5	
		HA	%	HA	%	HA	%	HA	%	HA	&	HA	%	HA	%	HA	%	HA	%
Pre-M	200	270	35	271	36	282	41	384	74	334	67	432	116	375	88	426	113	460	130
Monsoon	758	926	22	941	24	940	24	1238	63	1015	33	1015	34	1181	56	1155	52	1463	93
Post-M	–	46	–	45	–	49	–	57	–	57	–	76	–	65	–	73	–	127	–
Annual	906	1066	17	1143	26	1202	32	1391	54	1350	49	1636	86	1471	62	1591	75	2181	140

*HA = heat accumulation.

management, and direct the future researcher to conduct more precise and region specific climate studies to access local climate risks.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.atmosres.2018.01.009.

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